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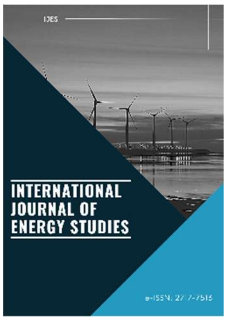

Research Article

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Experimental and numerical investigation of different wing profiles

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Highlights

- The aerodynamic properties of the wing profiles were determined theoretically.
- Analysis of aerodynamic properties of airfoils in Computational Fluid Dynamics (ANSYS-Fluent) program.
- Comparison of aerodynamic properties of airfoils with experimental data and Computational Fluid Dynamics calculations.

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ABSTRACT

Computational Fluid Dynamics (CFD) techniques are widely used in product development processes due to efficient algorithms to solve Navier Stokes equations. In this study, the coordinates of the NACA 1412 and NACA 2415 sections selected from the standard wing sections of the National Aviation Advisory Committee (NACA) have been implemented with specific procedures to create new geometries and a new wing profile design using the coordinate method. The wing profile geometry is created from the coordinates available in the literature. Fixed two-dimensional viscous flows around the generated wing profiles are simulated using commercially available ANSYS-Fluent software. The mesh structure used was created using the C type and rectangular structure. CFD and wind tunnel analysis of attack angles ranging from certain degrees. The aerodynamic coefficients of the related statuses, i.e. the lift and drag coefficients obtained from the analysis, have been compared with the wind tunnel test results. Aerodynamic research in recent years focuses on active flow control concepts, laminar flow control, fuel economy and higher transport/drag force ratio. This is designed to understand and analyze flow behavior around airfoils using the CFD method.

Keywords: Aerodynamics, Airfoil, Computational fluid dynamics (CFD)

1. INTRODUCTION

With the increase in investment in technology in recent years, the use of unmanned aerial vehicles, which is also on the agenda of the aviation industry, has increased. In general use of UAVs, it is necessary to design with the lowest weight for the optimum range [1].

In recent years, as technology has advanced, the use and demand for UAVs for a variety of purposes has grown quickly. War zones and reconnaissance are where this requirement is primarily concentrated.The best image processing with the longest range and lightweight design are used in this study to examine UAV wing designs which are applicable to all atmospheric conditions. Airfoil optimization is the most crucial aspect of aerodynamic design, which is the first step in the design of an aircraft. It is expected that standard design methods would be utilized to evaluate UAV airfoils before doing wind tunnel experiments [2]. Measurements made using Particle Image Velocimetry (PIV) in the wind tunnel are also being researched [3].

The rapid improvements to computer technology, however, are leading to an increase in Computational Fluid Dynamics (CFD) applications because these procedures demand a lot of workforce and financial resources. For these reasons, CFD technologies are adopted and become popular in airfoil analysis [2,4,5]. Due to the increased use of CFD analysis, changes in aerodynamic parameters are now accessible by searching at aircraft wings, including bird strikes [6].

Experimental and computerized studies of the wing designs used in the study were carried out. Aerodynamic parameters and information used for UAVs;

A 2D cross section of an item moving in a fluid, such as a wing, a propeller, a rudder, or a sail is called an airfoil. They are curved or straight, typically drop-shaped parts made to provide the best lift/drag ratio for a vehicle moving in a fluid like air or water. According to Bernoulli's principle, airfoils often cause a pressure differential on two sides of the item that are at an angle to one another. Aerodynamic forces are produced in this manner, keeping the airplane in the air [7].

Weight is one of the most important aerodynamic factors. Lift is the ultimate consequence of the aerodynamic resultant force that is parallel to the wing surface. The aircraft is kept in the air by this force [8]. In order to create maximum lift, we need to bring the weight of the aircraft to a minimum. By reducing the weight of the wing profile, it allows us to achieve more efficient and higher performance of the aircraft. Especially when we use composite materials for aviation materials, we create a durable and light structure. Chakraborty and Ghosh analyzed the effect of lift force on NACA 2412 airfoil structure with Carbon Fibers, Alpha-Beta Titanium alloy and Al-Zn-Mg materials in ANSYS program [9].

Drag is the aerodynamic resulting force's horizontal component. It is the force that arises from static locations on the aircraft and air flow frictions and moves in the opposite direction to the direction of the aircraft [10].

By changing the shape of the wing profiles, the drag force can be reduced. Long-haul flight is thus possible. For this reason, drag-reducing airfoils can be created [11]. When the wing profiles are analyzed aerodynamically, adaptive wing structures are applications developed according to the requirements of different drag and lift forces according to the desired situation in flight. Morphing wings; wing aspect ratio, airfoil camber ratio, wing area and even different parts of the wing are applications that allow different angles of attack to be obtained. Studies have begun to show that UAVs can save energy and time by having shorter take-off distances, more efficient operation at low revs, reduced stall speed, and reduced drag force, even though modern airplanes like the Boeing 777-X use transforming wing geometries [12].

The lift force measured in a wind tunnel differs from the lift force estimated numerically for an airfoil structure. The lift force coefficient (C_L) is utilized in the calculations to account for this discrepancy when computing the lift force [10]

The drag force of an airfoil construction as estimated theoretically differs from the drag force as observed in a wind tunnel. The drag force coefficient (C_D) is utilized in the computations to take this discrepancy into account when determining the drag force [10]

2. MATERIAL and METHOD

New wing profiles were produced as a result of the adjustments made to the coordinates of the wing profiles acquired from the conventional wing sections. With the developed wing profiles, CFD analyses were carried out using the commercial program ANSYS-Fluent. The wind tunnel was also used to perform flow analyses on the designed wing profiles. The analyses that were performed led to comparisons between the lift and drag coefficients that were derived from the investigation of the aerodynamic coefficients of the pertinent scenarios.

2.1. Generating New Geometries from Standard Wing Sections

The coordinates of the NACA 1412 and NACA 2415 sections, which were chosen from the list of conventional wing sections, underwent a number of procedures. The region at the top of the wing section is expanded in order to improve the hump ratio, and as a result, the air traveling over the section moves faster. According to the Bernoulli equation, the pressure lowers more as air velocity increases. The lift force increases as a result of this increase in the pressure differential between the wing's bottom and upper sections.

The wing sections in the NACA 1412 profile are 10% larger in the upper surface curve's y-axes and 15% smaller in the lower surface curve's y-axes. We got a brand-new section profile. The new section's top hump has grown, while the section's lower hump has been flattened.

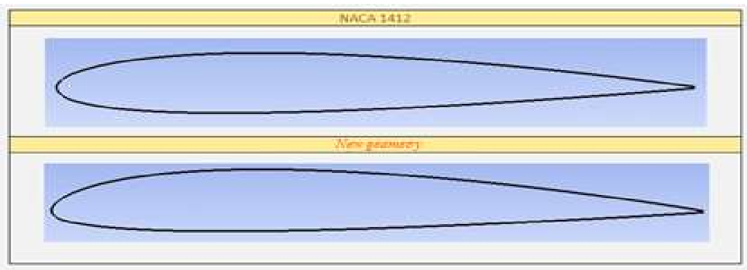

Figure 1. NACA 1412 and new wing section profile

The wing sections in the NACA 2415 profile are 20% larger in the upper surface curve's y-axes and 25% smaller in the lower surface curve's y-axes. The new section's top hump has grown, while the section's lower hump has been flattened.

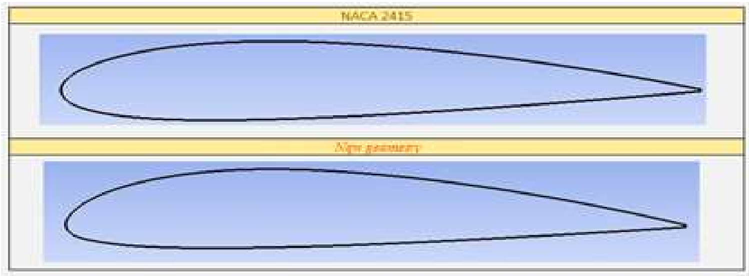

Figure 2. NACA 2415 and new wing section profile

The coordinate approach was used to create a novel airfoil outside of the typical blade sections at the same time. The name of this airfoil is MASA. Figure 3 shows it.

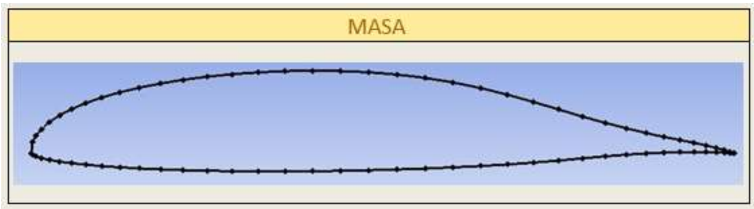

Figure 3. MASA wing section profile

2.2. Analysis of Created Airfoils Using CFD

In this study, two-dimensional geometries of airfoils were created. The areas of the flow region were drawn by using the C-type mesh flow area geometry in Figure 4.

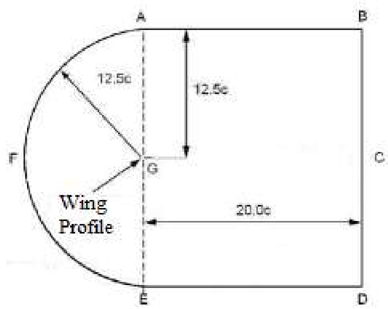

Figure 4. Wing section geometry around the flow area (C-mesh)

After this geometry obtained (consisting of wing cross-section and flow area) is included in the mesh program, the flow area is divided into cells (mesh). Smaller cells were formed on the wing cross-section surface and cells that grew further away from the geometry (Figure 5). Each cell can be thought of as very, very small control volumes for which the conservation equations are solved.

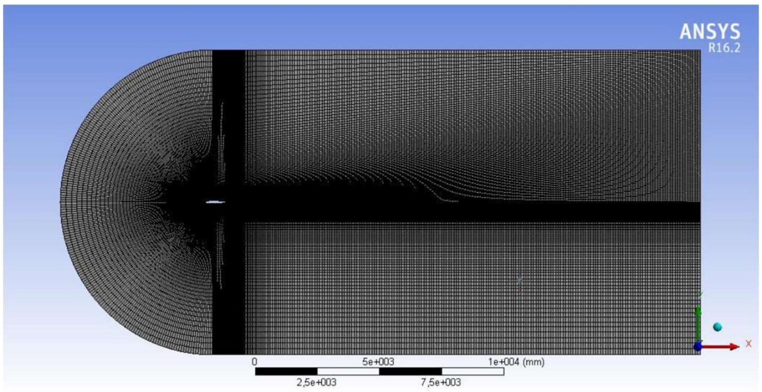

Figure 5. Mesh structure

When the condensed mesh thrown into the system is examined in terms of quality according to the Aspect Ratio parameter, the "Average" value is 3,5316 in that Figure 6. This value shows us that the mesh structure we created can be considered good.

Table 1. Value of the aspect ratio parameter

Value of the Aspect Ratio Parameter	
AR=1	Excellent Mesh
1 < AR < 3	Good Mesh
3 < AR < 10	Acceptable Mesh
AR >10	Unacceptable Mesh

Statistics	
Nodes	71710
Elements	71120
Mesh Metric	Aspect Ratio
Min	1,0004
Max	235,27
Average	3,5316
Standard Deviation	3,5877

Figure 6. Airfoils aspect ratio mesh quality values

By setting border regions and boundary conditions. The drag and lift coefficients were determined between 0 and 20 degrees angle of attack at a low speed of 20 m/s.

The lift and drag coefficients of these wing sections obtained by CFD are discussed in detail with the graphics below.

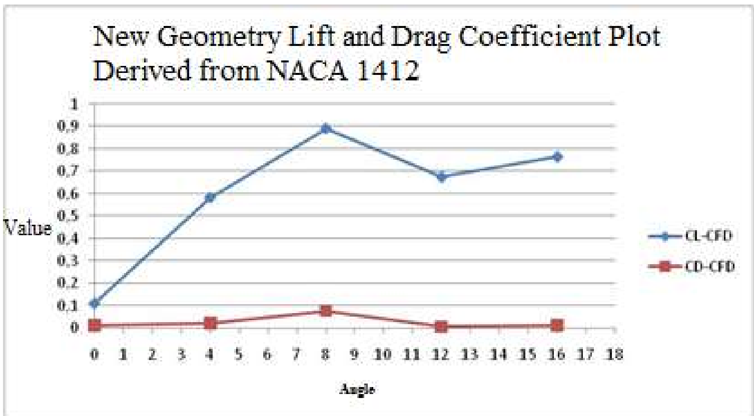

Figure 7. New geometry lift and drag coefficient plot derived from NACA 1412

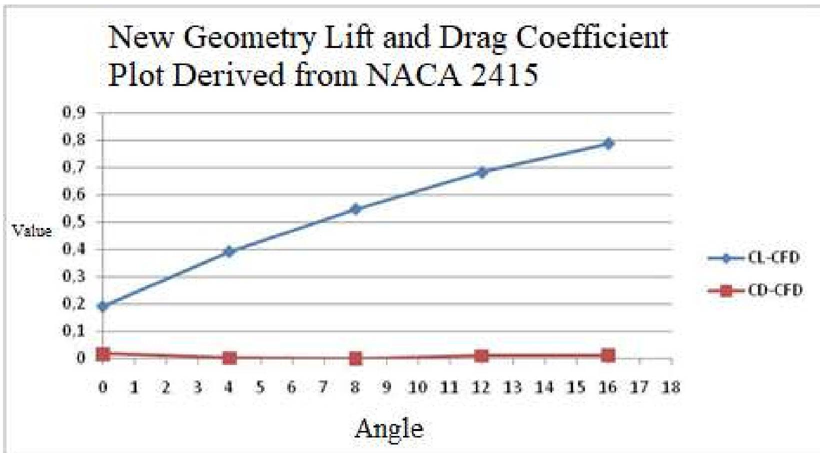

Figure 8. New geometry lift and drag coefficient plot derived from NACA 2415

2.3. Wind tunnel testing

The purpose of the wind tunnel is to study and interpret how objects in the air or another gas interact with the air flow. They are tunnels where the speed of the moving air can be changed. The items in the wind tunnel are impacted by moments and aerodynamics. In terms of design, it is crucial to establish these aerodynamics and moments as well as the configuration and form of the air flow. In a safe and efficient setting, wind tunnels are used to gather data on air flow.

Wind tunnels can be used to analyze the aerodynamic structures of prototype items that are real-size or scaled down. With the advancement of technology, these tunnels, which were previously primarily used for aviation parts, are now utilized to determine bullet constructions, the forms of high-speed road and rail vehicles, and the computation of wind loads for skyscrapers and bridges.

Figure 9. AF-100 wind tunnel

Table 2. TecQuipment AF100 subsonic wind tunnel features

Nu.	Technical Specification	The Reference Range
1	Electric supply (3 phase)	220 VAC to 240 VAC 50 Hz/60 Hz (20 A) or 380 VAC to 440 VAC 50 Hz/60 Hz (16 A)
2	Operating temperature range:	+5 °C to +40 °C
3	Operating relative humidity range:	80% at temperatures below 31 °C, 50% at 40 °C
4	Net measurements and installed weight	3700mm x 1065mm. x height 1900mm and 293 kg
5	Wind tunnel test volume	305 mm x 305 mm in area and 600 mm in length.
6	Airspeed range	0-36 m/s

Powerful fans are used in several wind tunnels to force air through the pipe. The test object is positioned in the tube and left immobile. We may refine our aerodynamics by observing the air flowing around the item in the tunnel. There are several techniques to observe the movement of the air. In these techniques, smoke or paint can be added to the air, or the air movement can be seen by tying ropes to the item.

The studies were conducted in the National Defense University's AF100 model subsonic wind tunnel, which bears the TecQuipment name. Figure 9 illustrates the relevant experimental setup. Open circuit, vacuum, and computer-based data collecting are features of the employed wind tunnel. Through an aerodynamically constructed cone that is linearly propelled, air enters the wind tunnel. The air arriving from here travels through the working area before being discharged back into the atmosphere.

This wind tunnel can be used to conduct a wide range of subsonic aerodynamic experiments. These include drag force and buoyancy calculations, boundary layer surveys, flow visualization, and others. There are numerous aerodynamic analyses carried out. We calculated the lift and drag force in this wind tunnel and looked at the pressure distribution around an airfoil.

2.3.1. Airfoil model construction

Three-dimensional computer-aided design (CAD) data was used to generate the physical models of the wings. The physical models' employment in the wind tunnel guided the creation of the dimensioning procedure and connection locations. The finished airfoils' designs have been saved in STL file format. The Cura program changed the STL file format data into a format that could be printed on a 3D printer.

The physical models used in the experimental setups were manufactured using a 3D printer.

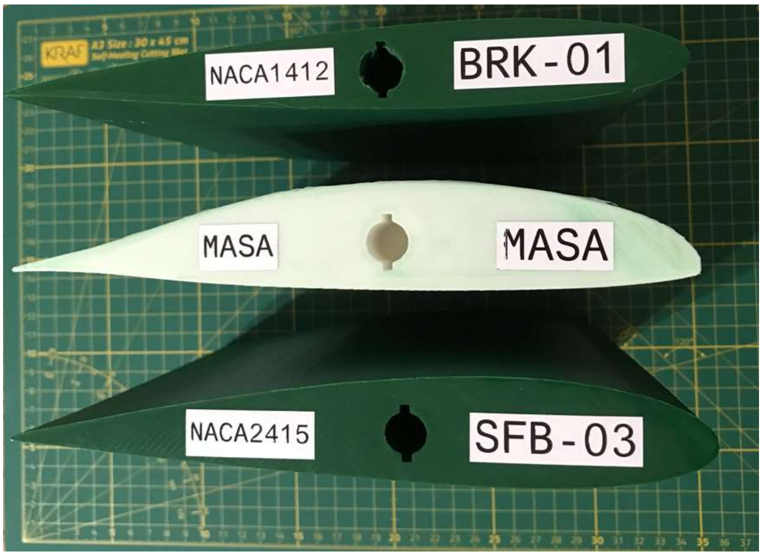

Figure 10. 3D printed airfoils

2.3.2. Analysis of created airfoils in a wind tunnel

The wing profiles were modeled using a 3D printer. Modeled wing profiles were printed at 200 mm x 200 mm. The relevant models were prepared for the wind tunnel test by completing the surface preparations for the wind tunnel. C_L and C_D values are obtained by increasing the profile, which is mounted in the wind tunnel, to 0, 3, 6, 9, 12, 15, and 18 degrees, respectively, starting from 3 m/s speed at each angle and increasing by 3 each, up to 36 m/s. In Figure 9, the visuals of the wing models in the wind tunnel are added.

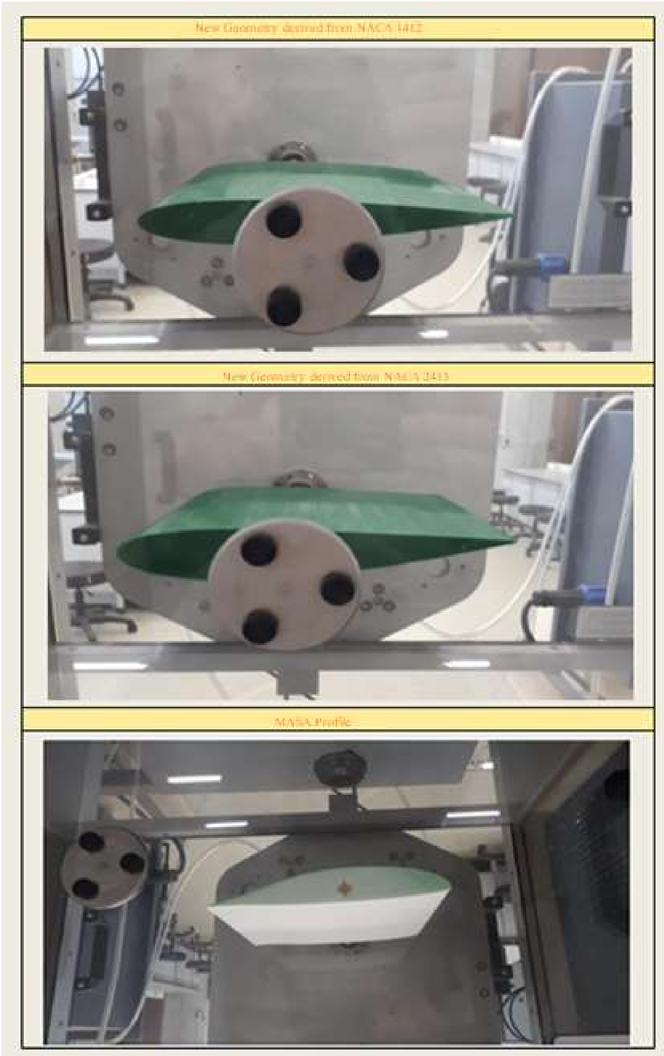

Figure 11. Models of wings in the wind tunnel

The C_L and C_D graphs below were obtained by analyzing the received data.

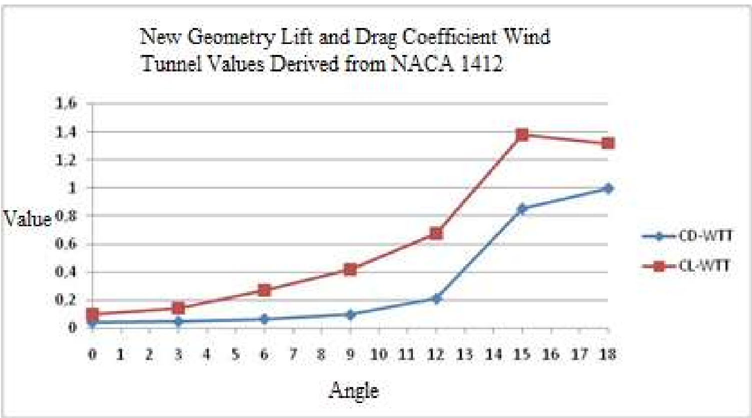

Figure 12. New geometry lift and drag coefficient wind tunnel values derived from NACA 1412

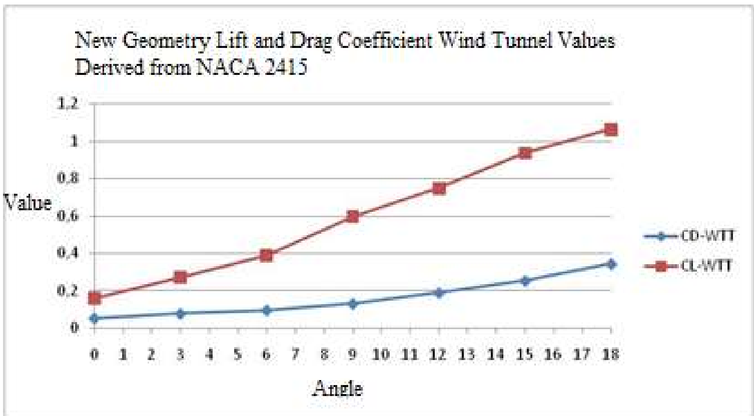

Figure 13. New geometry lift and drag coefficient plot derived from NACA 2415

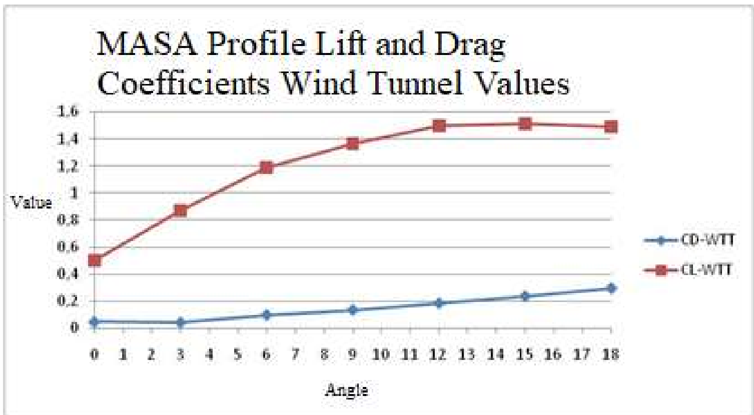

Figure 14. MASA profile lift and drag coefficients wind tunnel values

3. RESULTS AND DISCUSSION

The graphics below show a comparison between data obtained by CFD and data obtained from a wind tunnel.

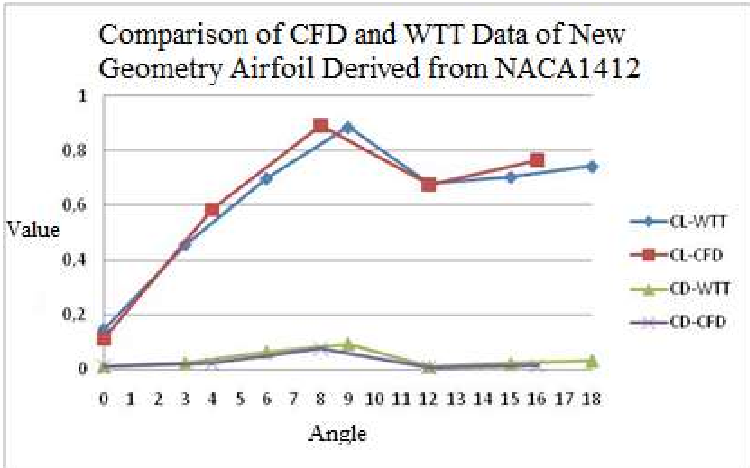

Figure 15. Comparison of CFD and WTT data of new geometry airfoil derived from NACA1412

Comparable curves between numerical and experimental data in the graph shown in Figure 15. It was observed that the lift coefficient increased with the increase of the angle of attack up to a certain limit, and then it decreased experimentally, but the lift coefficient increased numerically. However, numerically, it is seen that the lift coefficient is slightly closer to the experimentally obtained value. The friction coefficient experimentally increases with the increase of the angle of attack, and furthermore the numerical value of the drag coefficient remained very close up to the angle of 12 degrees.

However, the amount of experimental data increases excessively after 12 degrees. It is necessary to use sophisticated turbulence models to investigate this situation. According to the graph above, the buoyancy coefficient at a 12 degree angle of attack is 0.674. This numerical value of 0.677, which was obtained experimentally, is very close to it.

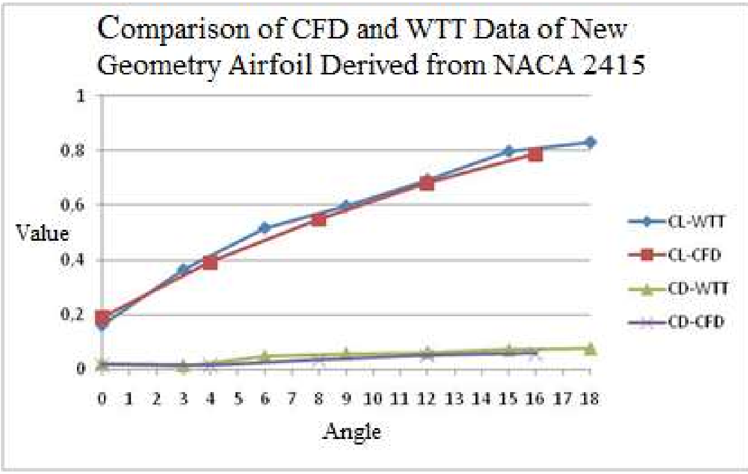

Figure 16. Comparison of CFD and WTT data of new geometry airfoil derived from NACA 2415

Comparable curves between numerical and experimental data in the graph shown in Figure 16. It is seen in the figure that the lift coefficient increases as the angle of attack increases up to a certain limit. The coefficient of friction experimentally increases with the increase of the angle of attack, and furthermore the numerical value of the coefficient of drag remains very close up to the angle of 12 degrees. The graph above shows that the buoyancy coefficient is 0.681 numerically at 12 degrees of attack angle. This experimentally obtained data of 0.749 is close to the numerical value.

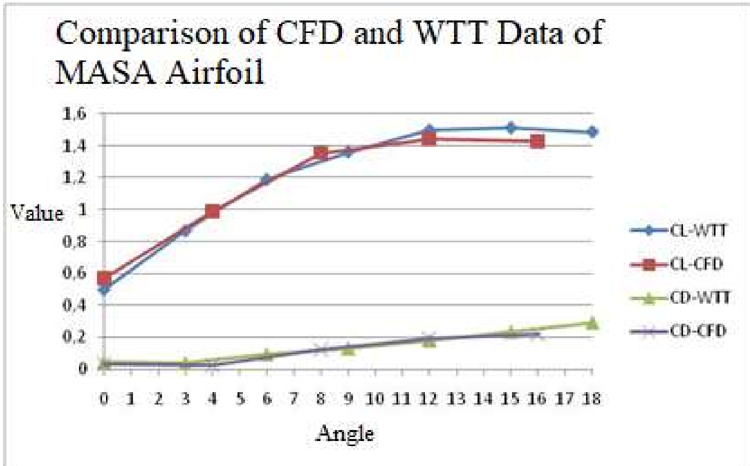

Figure 17. Comparison of CFD and WTT data of MASA airfoil

Comparable curves between numerical and experimental data in the graph shown in Figure 17. It is seen in the figure that the lift coefficient increases as the angle of attack increases up to a certain limit. The coefficient of friction experimentally increases with increasing angle of attack. At the same time, when the data is examined on the graph, it is seen that they are compatible with each other. If we compare the numerical values at 12 degrees of attack angle, it is seen that the buoyancy force coefficient is 1.441 numerically and 1.498 experimentally.

4. CONCLUSION

After the analysis carried out on the wing profile, it was decided to use the MASA profile. Here, as a result of both CFD and wind tunnel tests, the most efficient airfoil to be used was examined. When CL/CD of 3 different airfoils were compared at a 4 degree angle of attack, the value of the MASA profile was found to be 41.16. When we look at the other wing profiles, it is seen that the derived from NACA1412 wing profile is 25.50 and the derived from NACA 2415 profile is 26.10. It has been observed that the CL/CD value of MASA profiles is 2 times higher than other airfoils. MacEachern et al. also stated that lift and drag ratio is the most important issue on the design of the wings and a high C_L/C_D value is always desired in the wing studies [13].

Airfoil study was carried out in order to have higher aerodynamic efficiency. In this study, it has been determined that different types of airfoils provide improvement in aerodynamic performance parameters in applications. As a result of our decreasing stocks of raw materials and the increase in the cost of fossil fuels, fuel economy has become necessary. While performing these parameters, it should also increase the flight comfort. Therefore, the aviation industry will develop.

NOMENCLATURE

CFD	Computational Fluid Dynamic
WTT	Wind Tunnel Test
C_L	Lift coefficient
C_D	Drag coefficient
NACA	National Aviation Advisory Committee
UAV	Unmanned aerial vehicles

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DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Murat ŞAHİN: Academic advisor

Mehmet Arif SALTAN: Performed the experiments and wrote the manuscript.

Burak Berk BAŞKAYA: Performed the experiments and analyse the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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